GLACIAL STUDIES IN GREENLAND. IX.

WITH one exception — the Igloodahomyne — the glaciers thus far studied have been dependencies of local ice-caps. Those first sketched were connected with the snow fields of the island of Disco. Those which we have just been considering were offsprings of the snow-cap of the Redcliff peninsula. We are now about to turn to the tongues, lobes and border of the great ice mantle of Greenland.

The order of study we have pursued has certain elements of advantage that may be noted before we pass on, as it may be helpful in giving significance to our further observations. The local glaciers of Disco were found to present sloping borders, after the usual style of southern glaciers. It would appear that this mode of termination is the dominant habit of the glacial border in southern Greenland, but I was not permitted to make observations which justify me in asserting this, and the writings of others do not seem to be sufficiently specific on this point to warrant an unqualified affirmation. The glaciers of Disco have much the same limitations in size as the glaciers of southern alpine regions, and this may possibly give occasion for the inference that the element of magnitude is a controlling one in determining the marginal habit of a glacier. In view of this possible appeal to magnitude as an element of interpretation, it is fortunate that we have been able to study glaciers of like dimensions in high latitudes. It may be safely inferred, therefore, that the differences in the verticality of the glacial margin, which we have found so pronounced, and in the basal stratification (if this difference really exists) are not functions of magnitude.

In like manner it is of some importance to know whether the differences in the magnitude of the glaciers of the northern field, when compared with each other, are correlated with any impor-

tant variation in the mode of their deployment. If it shall appear that there are no essential differences between the action of small ice-caps and large ones, an important gain to interpretational methods will have been realized; for, if magnitude does not constitute an important source of difference in mode of action in high latitudes, it probably does not in low latitudes, where only small glaciers exist and comparisons in magnitude are impossible beyond the narrowest limits. In so far as a comparison of the foregoing small ice-caps and their dependencies with the great ice-cap and its dependencies, yet to be described, contributes to the adjudication of the element of magnitude as a factor in glaciation it subserves a function to which few contributions have been possible heretofore.

It will of course not be overlooked that there is an important distinction between the small glaciers which we have just studied and the small alpine glaciers that have been the chief subjects of study in southern latitudes. The glaciers of Redcliff peninsula all radiate from a common ice-cap gathered upon a plateau of moderate elevation. The glaciers of like magnitude of southern latitudes hang on mountain slopes or nestle in mountain valleys. The nearest approach to an ice-cap in these regions is found in the snow fields that mantle the mountain cols. The rugged environment of the alpine glaciers has given to them a burden of superficial detritus which very much obscures their basal features and has imposed a constraint in deployment which very much distorts their normal evolution. From these restricting conditions the glaciers of the Redcliff peninsula are almost wholly free.

A special point of comparison between small and large ice-fields, of supreme importance in its bearings on the interpretation of the drift of the Ice Age, is the mode of introduction and transportation of rock débris. The small fields show us these phenomena as executed in short distances; the great fields, in long distances. The diameter of the Redcliff peninsula is not more than fifteen miles; the diameter of the great ice-cap is 700 miles, a ratio of about one to fifty. None of the material

borne out by the radiating glaciers of the Redcliff peninsula can be supposed to have been carried more than six or eight miles. Some of that borne out by the great inland sheet may have been carried three or four hundred miles.

If, in the descriptions and illustrations that follow, it shall be found that the interlamination of débris in the base of the great ice-cap is of the same nature and degree as that of the small ice-caps we have just studied, it will seem to be a safe inference that this intrusion of débris has narrow limitations in its development and is not at all proportional to the magnitude of the ice body with which it is connected. The point is one of fundamental importance, for it has a decisive bearing on the radical question whether the ratios of free to loaded ice which are found to obtain in the small glaciers can be applied to the great ones that are now extinct. If, for instance, it is found that a glacier which is no more than six or eight miles in length is well inset with débris to the height of fifty or sixty, or even one hundred feet, from its base, it might be inferred—indeed it has been inferred—that a glacier 300 or 400 miles in length might be filled to a proportional height, *i. e.*, to 2500 or 3000 or even 5000 feet. If such a law of ratios holds true, we shall find the glacial lobes and border of the main ice-cap exhibiting an interlamination and a burden of débris of a truly magnificent order.

The purpose of this discussion, at this point, is to quicken observation on the illustrations of the great ice-cap, and of its lobes and tongues, to which we now turn.

The Tuktoo glacier.—The general form and relations of the Tuktoo glacier may be best apprehended by reference to the maps opposite pp. 198 and 669 in preceding articles. It will there be seen that it is simply a lobe of the main ice-cap descending from the north to the lowland which constitutes the neck of the Redcliff peninsula. Its movement is directly opposite to that of the Krakokta glacier last described, which descends the north slope of the Redcliff plateau. These two glaciers come into direct conflict and form the most interesting joint terminal

moraine already described in connection with the Krakokta glacier (p. 836). In view of the considerations above noted, the

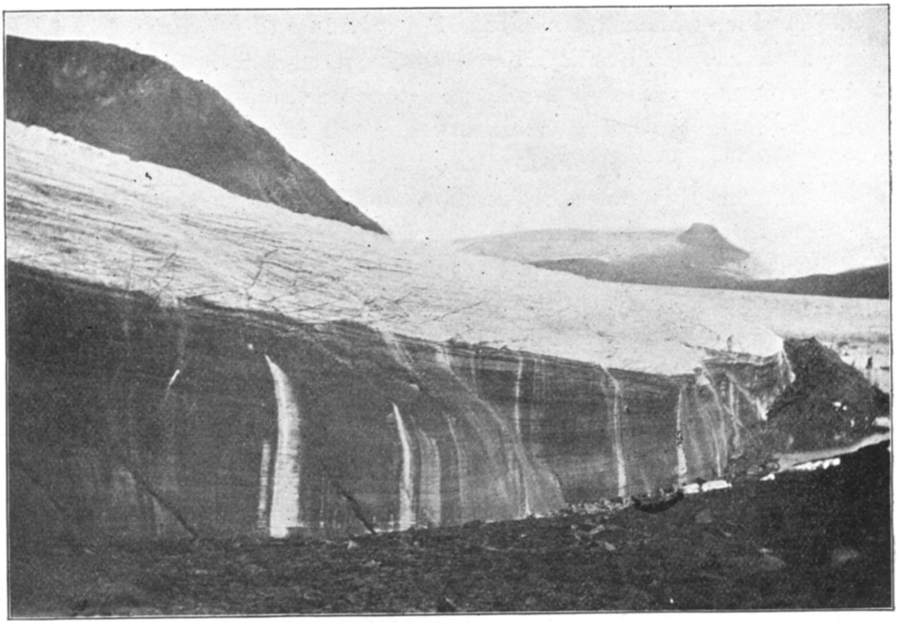

FIG. 60.—View of the south side of the eastern lobe of the Tuktoo glacier seen from a point on the lower slope of the Sentinel nunatak, looking northeasterly. The smooth, nearly vertical wall of the glacier is seen in the foreground with the crevasses running from left to right with an inclination forward. Crossing these in the upper part of the glacier may be seen numerous lines running from left to right obliquely upwards and backwards, and curving toward the glacial axis in measurable conformity to the configuration of the ice. At the right hand in the foreground is seen the terminal moraine mantling a base of ice, and also a portion of one of the lakelets mentioned in the text. Beyond this moraine is seen the Bowdoin glacier which is separated from the Tuktoo glacier by a depression and by the moraine just mentioned. The eminence in the background at the left is the Sierra nunatak. The eminence in the distant center is the Sugar Loaf which stands on the border of the inland ice field. The lobe obscurely seen on the right is the Mirror glacier. The moraine from which Mr. Peary took his departure on his last trip across the great ice field may be seen obscurely, perhaps, at the right of the illustration, nearly opposite the Sugar Loaf.

reader is invited to turn back to the figure on the page cited and compare at a single glance a glacial lobe of the great ice-cap and a glacial lobe of a very small ice-cap. It will be difficult to

find any essential difference between the structure, the débris burden, or the mode of action of the two glaciers. The moraine is very symmetrical and shows no preponderance of action on either side. The right-hand slope is made up of gray crystalline rock contributed by the lobe of the great ice-sheet, and the left-hand slope is made up of red sandstone contributed by the lobe of the little ice-sheet. The work of each is perfectly declared and is singularly balanced.

If from this point of junction and conflict we turn to the right and follow the border of the Tuktoo glacier, we shall find it holding aloof in a measure from the Sentinel nunatak whose base it skirts. A vertical wall faces the nunatak throughout the entire arc skirted by the glacier. At no point does the ice press hard against the sides of the mountain. On the west angle it rises somewhat on the foot slope but does not close up the fossa between the ice and the mountain.

Our first illustration (Fig. 60) is taken from the base of the nunatak looking northeasterly obliquely across the south face of the eastern lobe of the glacier. It will be seen that the vertical wall possesses the same features of interlamination of débris in the basal part, and of freedom from débris in the upper part, which has so generally characterized the glaciers previously described. The face here is the smoothest and most strictly vertical which I observed in Greenland, and the amount of interlaminated débris is notably fine in grain and small in amount. The absence of a moraine or talus slope at the base (except at the extremity) will be noted. The interlamination of detritus reaches to the height of about seventy-five feet above the base. Although an offshoot of the great ice-cap, it is to be noted that the débris does not rise higher than in the glaciers from the small Redcliff ice-cap. The amount of the included débris happens to be here somewhat less than that in most of them.

In describing the upper Blase Dale glacier of the island of Disco (p. 785, Vol. II) note was made of numerous fracture lines traversing lateral portions of the glacial surface in a direction at variance with, indeed transverse to, the normal course of

crevasses in such a position. A similar system of fracture lines is observable on the side of the Tuktoo glacier facing the Sentinel nunatak. The general nature and course of these may be made out from an inspection of Fig. 60, but the details are bet-

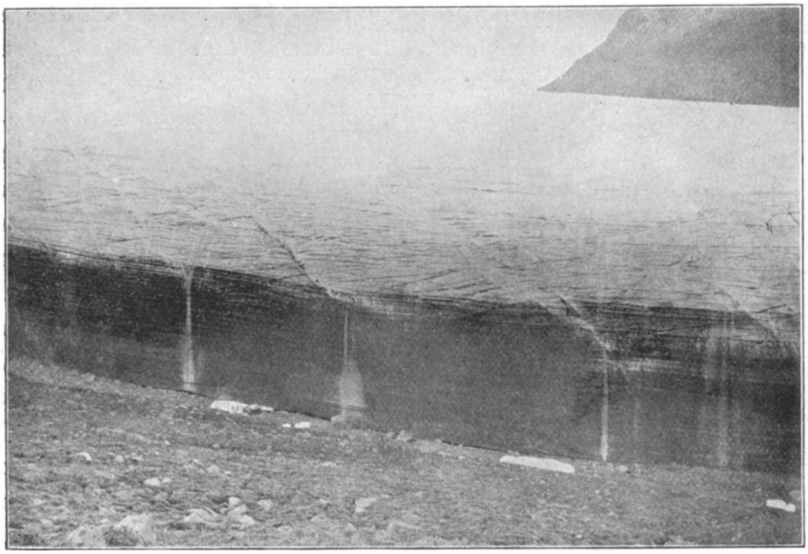

FIG. 61.—A nearer view of the south side of the eastern lobe of the Tuktoo glacier from a photograph by Professor Libbey, showing the verticality of the wall, the absence of a moraine at the base, the crevassing in a moderate degree, having the direction usually taken on the side of a glacier, and, particularly, the non-gaping crevices, running transverse to the crevasses.

ter seen in Fig. 61. In the upper part of the glacier it will be observed that there are numerous oblique fracture lines starting within the dark band which represents the vertical wall of the glacier and running obliquely backward and upward, curving toward the axis of the glacier. It will be seen that these cross the layers of the ice, which are shown by light and dark banding on the vertical side and by parallel ridgings on the upper surface of the glacier. The normal system of crevassing may be seen imperfectly by the gaping fissures on the side of the glacier at the left in Fig. 60. They are also indicated by the

streams that issue on the face of the glacier in the center of the figure. These follow the crevasses until they reach the face of the glacier, when they descend it vertically. (It may be remarked in passing that the whiteness of the track of these little streams as they descend the side of the glacier indicates the relative purity of the ice. The blackened, unwashed surface shows the extent to which the fine débris, when freed by slow melting, covers the surface and invites an illusive impression of its amount.) Fig. 61, from a larger photograph taken by Professor Libbey, shows more satisfactorily both the normal, gaping crevasses and these unopened crevices, and displays at once their differences in nature and in direction. By inspection of this figure it will be seen that these crevices extend to depths quite comparable to those reached by the crevasses, though they are individually less persistent. It will be observed that they usually terminate at a bedding line or at a fellow crevice and that they very much resemble the jointing of certain tilted rock beds. In some instances faulting appears to be indicated.

As remarked in the case of the upper Blase Dale glacier, the stress or tension which caused these crevices was not of such a nature as to require the gaping of the crevice after it was formed. In this respect, as well as in their direction, they differ from normal crevasses. It will perhaps be best to reserve a discussion of the cause and significance of the phenomenon until the remaining glaciers are described and the general subject of interpretations and inferences is taken up.

The two photographs show imperfectly a horizontal lining or ridging of the retreating surface of the glacier above the vertical face. These lines really represent a series of small terraces, the vertical faces of which rise a foot or so in height and the upper faces of which range up to a dozen feet in width. These terraces are really the obliquely outcropping edges of the glacial strata and are developed into the terrace form by differential melting of the ice, much as steps in stratified rock are developed by differential erosion. Their attitude is due to the upward curving of the layers of ice as they come to the surface, in accordance with

the habit of the glaciers of the region. These little terraces were so pronounced that one instinctively follows them in walking upon the upper surface of the glacier if his course lies at all coincident with them.

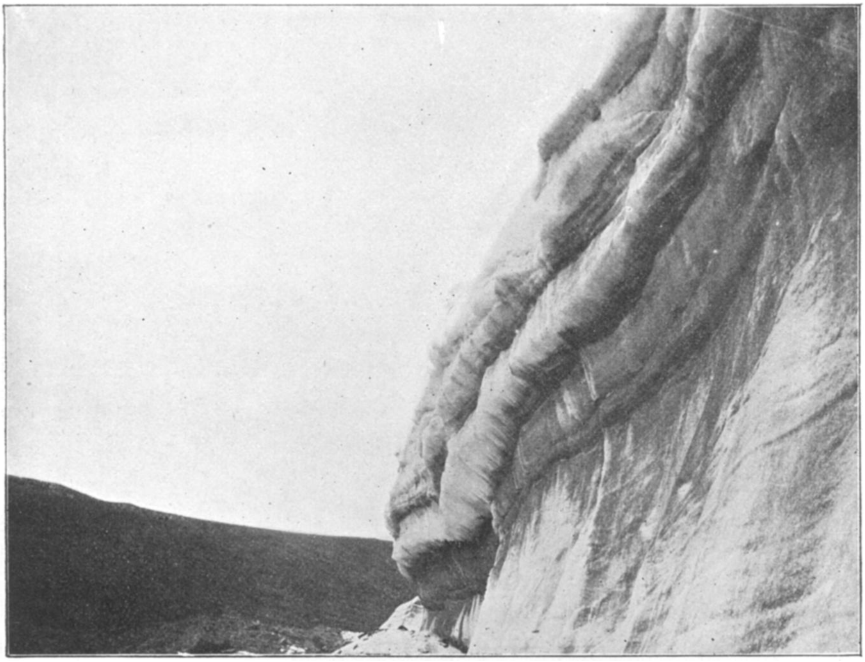

FIG. 62.—View of the terminal face of the Tuktoo glacier at the southeastern curve of the eastern lobe, showing the projection of the upper layers over the lower and the attendant phenomena.

An inspection of the base of the glacier as shown in Fig. 61 gives emphasis to the remark already made respecting the smallness of the débris in the ice and the absence of a lateral moraine. Following the face to the right, however, it will be seen that at a point where the border curves about to form the terminal face of the glacier, as shown in Fig. 60, there is a notable accumulation of débris in the form of a terminal moraine. This, however, is deceptively large, as the mass of the ridge is composed of ice concealed beneath a veneering of rock rubbish.

This terminal deposit extends around the extremity of the glacier to the Sierra nunatak which is seen in the background of the illustration, at the left.

The wall of the glacier, which in the foreground of the illus-

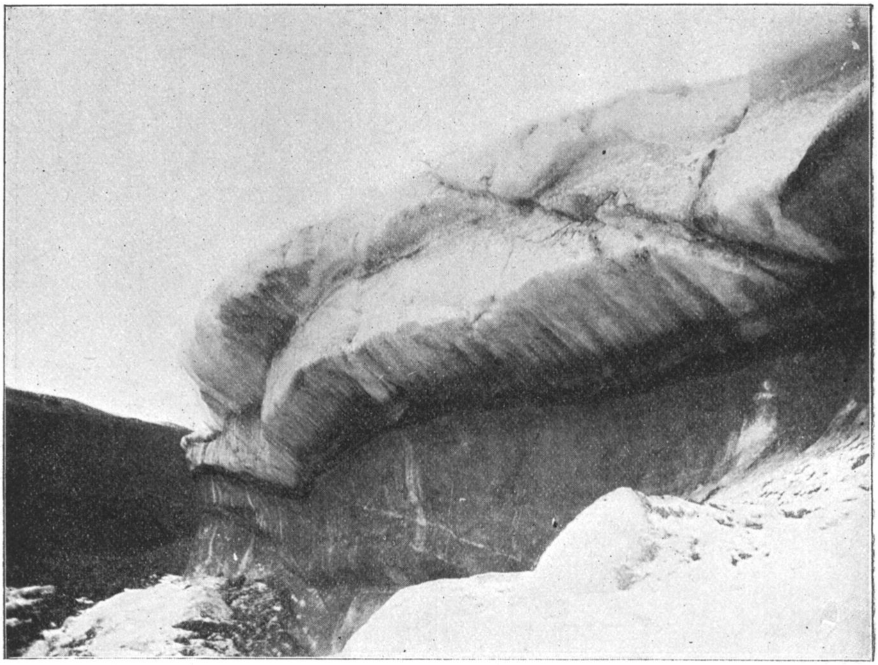

FIG. 63.—Another view of the terminal face of the Tuktoo glacier at the south-eastern curve of the eastern lobe, showing a more marked projection of the upper layers over the lower with the fluting of the under-side of the layers.

tration is so smooth and vertical, becomes irregular and overhanging at the extremity. This irregularity consists essentially in the projection of the upper layers over the lower. This overprojection reaches an extent of twelve or fifteen feet and takes on the aspects which are so well illustrated in the reproduction of photographs 62 and 63 as to leave little need for verbal description. The projecting portions consist of thick beds of nearly clear ice separated by seams of dirty ice. The phenom-

ena naturally raise the question whether the projection of the upper layers is due to actual overthrust of the upper layers or merely to the more rapid melting of the lower layers, or to a combination of the two. There is no question but that the dirty layers absorb the solar heat with more facility than the cleaner ice and are melting backward more rapidly, and that some of the irregularities which the vertical faces of this and other glaciers present are due to this differential melting. There is, on the other hand, little room for doubt that the upper layers of the glacier move faster than the lower ones. This is in accord with the generally accepted doctrine that the upper portion of a glacier moves faster than the lower, a doctrine based upon observation as well as theory. It is, however, an open question whether the differential motion is localized along the planes which separate the layers, or whether it is distributed through the mass. It is not advisable to enter at length upon the discussion of the question here, but these very striking phenomena merit special study with reference to it. It will be observed that the undersides of the projecting layers are distinctly fluted. This might easily be interpreted as a demonstration in itself of the movement of the upper layers over bowlder-shod under layers, resulting in the grooving of the over-running masses. It appears clear, however, that to some extent at least the fashioning of these flutings in the form in which they are now seen is due to the action of water descending the face of the glacier and flowing backward on the under side of the projecting layers. This does not, however, dismiss the hypothesis that the initiation of the fluting was due to differential motion between the layers. The fact that the débris has been carried in between the layers is in itself very significant respecting the hypothesis of one layer sliding over another. But this differential motion might have been confined to the point where the débris was carried in and may not be taking place in this terminal part of the ice. So this class of evidence, though it is pertinent to the general question of a shearing motion between the layers, is not altogether unequivocal in its application here.

Between the Tuktoo glacier and the Bowdoin glacier, which lies immediately east of it and runs transverse to this part of it, there is a valley in which has accumulated morainic material from both. The amount of this, however, is rather unexpectedly small when we consider the size of the two glaciers and the activity of the latter. Under this debris there is much ice and probably the two glaciers are in actual contact below it. Between the two glaciers and the adjacent nunataks there are two small lakelets of triangular outline, one lying on the right-hand side of the Tuktoo glacier, hemmed in between the two glaciers and the Sentinel nunatak, and the other on the left hand, between the two glaciers and the Sierra nunatak.

The vicinity of the nunataks afforded an opportunity to find a minimum measure of the height to which the ice formerly rose. Drift and glacial erosion were observed on the summit of the Sentinel nunatak up to a height of about 1600 feet. The extreme summit was much broken and riven and gave uncertain evidence whether it had been completely submerged or not.

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